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COOPER HEWITT
Industrial Lighting Studies

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BRIEF FOUR
Visual Acuity

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VISUAL ACUITY

ITS IMPORTANCE IN INDUSTRIAL LIGHTING

By E. LEAVENWORTH ELLIOTT

Why Do You Wear Glasses?

If you are one of the great majority who wear glasses you have a very definite idea of what "visual acuity" means: It is the result you get when you use glasses properly fitted to your eyes. Without the glasses the objects you see are more or less indistinct; the outlines are fuzzy, and the smaller details are so blended together as to be indistinguishable. Put on your glasses, and the whole field clears up; the fine details separate themselves, and all outlines become sharply defined.

When the oculist examines you he puts different forms of lenses before your eyes, and asks, "How do you see?" You tell him, "better," or "not so well." When he finds the lenses that give you the greatest visual acuity, as determined by your own judgment of how clearly you can see the test objects, he prescribes them for your use.

How Small an Object Can You See?

You know also that there are many objects that are "invisible to the naked eye"; in order to see them you must have the help of a magnifying glass. How large must an object be in order that the unaided eye may see it? That depends upon a number of conditions; first, upon how good a lens you have in your own eye; then upon the intensity of the light falling upon the object; and finally, upon the *quality* of the light by which you see it. Naturally, the eyes of different individuals vary in their ability to see small objects; or as it is expressed in scientific language, in their *resolving* power.

How Visual Acuity Is Measured

This resolving power is measured at an angle, as you can readily understand. You know that the farther away the object, the larger it must be in order for you to see it. Thus, if you just distinguish the object at A, Fig. 1, it will have to be of the size shown at B in order for you to see it at that distance. The resolving power of your eye is measured by the angle B E C. If your eye is as good as the average this angle will be about a minute, or sixtieth of a degree. All conditions being good, you can see a six-foot man a mile away.

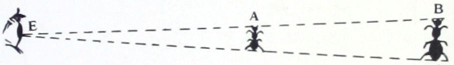

FIG. 1.

Diagram illustrating the visual angle.

How the Eyes Are Tested for Acuity

You will remember that one of the tests for fitting your glasses was to look at a sheet of paper on which there was printed a series of letters arranged in lines, which decreased in size with each line from the top. You probably noticed nothing peculiar about the letters, but they were all carefully selected and so drawn that their dimensions over all were the same, as also the width of the lines of which they were made up. These dimensions were such that when the chart was twenty feet away the

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height or width of the letters on a certain line subtended an angle of five degrees at your eye, and the thickness of the stems of the letters an angle of one degree. If you could plainly distinguish all the letters in this line your vision was "normal" as to acuity, or resolving power. If you could only read the letters in some of the lines above, your vision was below normal, and had to be helped out with glasses.

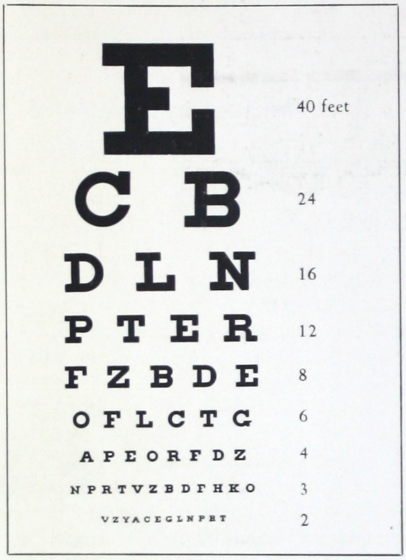


FIG. 2.

The "Snellen Chart," reduced to one-fifth actual size. This is the means commonly used by oculists in determining visual acuity. If you can read the different lines clearly at the distances given, you have "normal" acuity.

The smallness of the object which you can see is limited by the range of focus of the lens in your eye; as you bring the object closer to your eye you find a position beyond which you can no longer see it clearly, because the lens can no longer focus it. A microscope is a device which enables you to see the object at shorter range, and consequently of apparently larger size. The highest resolving power of which the eye is capable is reached with objects from 12 to 16 inches distant.

A Camera Which We Always Have With Us

Let us now turn our attention to the optical apparatus which we call the Eye. As you probably have been told, the eye is a little camera—more exactly, a stereoscopic camera. There is a lens in front, fitted with a stop, called the *iris,* and a sensitive surface, called the *retina,* at the back to receive the image. There is a means of focussing the image on this surface, and the eyelids act as a shutter.

The lens of the eye is a simple convex lens, or "bull's-eye." Such a lens has several inherent defects, or limitations. The one that concerns us here is its inability to bring the different colored rays to a focus on the same surface. If it focusses the red rays, the blue rays will be out of focus, and the others also to a less extent. Or, if it focusses the blue rays, the red, and the other colors to a less degree, will be out of focus. So, what the eye does when it has to handle light containing all the colors is to make a compromise and focus on the yellow, which is a mean between the two extremes of red and violet.

Yellow the Best Color for Producing Vision

Because the eye has always used this compromise in focussing with natural light, it has

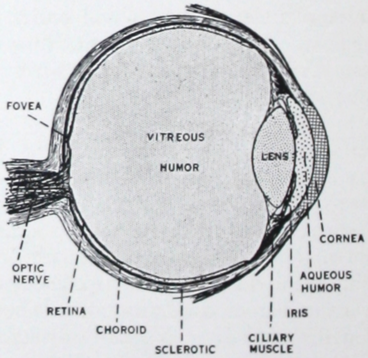


FIG. 3.

Diagram of a horizontal section of the left eyeball. The Cornea, Aqueous Humor, and Lens form the optical system corresponding to the lens of the ordinary camera. The retina is the inner lining, which forms the sensitive film.

become much more sensitive to the middle-range of color,—the yellow and yellow-green—than to the other portions of the spectrum; that is, it takes a less amount of energy in the form of yellow light to produce a given visual effect than it does of any other color. The relative visual effect produced by equal amounts of energy in the form of different colored light is shown by the curves in Fig. 8.

The inability of the eye to focus all colors at once is called *chromatic aberration*. It is possible to make glass lenses free from this defect, which are therefore called achromatic (non-chromatic). You can easily see the effect of chromatic aberration in any simple lens, such as a strong reading glass.

Sharpness of Vision Depends Upon Brightness, and the Kind of Light

It is a common experience that sharpness of vision falls off in dim light. As children, we have all been told, when the fascination of some story kept us reading after the twilight had deepened into dusk, "you mustn't read in that dim light, you will ruin your eyes." The warning was wise; as the light becomes dim the letters of the printed page lose their sharpness, and the only means the eye has of making up this loss in acuity is to increase their apparent size by getting closer to them. This unnaturally close range strains the focussing muscles, and tends to give the lens a permanent set, thus producing near-sightedness.

In order to see with the greatest sharpness, at least 10-ft. c. intensity is necessary.

The quality of the light also affects the resolving power of the eye. By "quality" is meant the kind of rays which make up the light. We commonly think of light as a simple thing; but in reality it is a complex mixture. The different ingredients are the different kinds of rays which we call *colors*. In the rainbow the compound which we call "white light" (sunlight) is "unscrambled," so that it shows the different kinds of rays which it contains,—red, orange, yellow, green, blue, violet, with every gradation of blending between them.

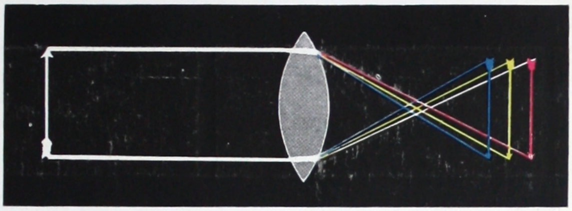


Fig. 4.

Diagram showing the effect of chromatic aberration. The rays of white light on passing through the lens, are separated into their different colors, each of which is brought to focus at a different distance from the lens.

How Light Is Analyzed

By passing a beam of light through a prism it can be separated into its constituent rays in the same manner. The band of colors so produced is called the *spectrum* of the light. If you look at the spectrum of an incandescent electric lamp you will see the same general scale of colors that you find in the rainbow, or solar spectrum. There will be some of the violet end missing, and the red and orange sections will be much brighter in comparison with the blue and violet sections. The different colors will blend into one another in the same way.

If now, you produce a spectrum of the light from a mercury vapor lamp you will see a very different thing. In place of the continuous band of blended colors you will see a number of *colored lines,* each in the same relative position as the like color in the solar spectrum. This mixture of the yellow, green and blue gives the light its peculiar bluish green color, characteristic of mercury vapor light. The spectra of sunlight and mercury vapor light are shown in the above illustration, as nearly as printing processes will permit. It must be remembered, however, that the bands thus shown represent the color only, and not their brightness. It is impossible to show the different intensities of light, except to a very limited extent, by any colored or shaded non-luminous surface.

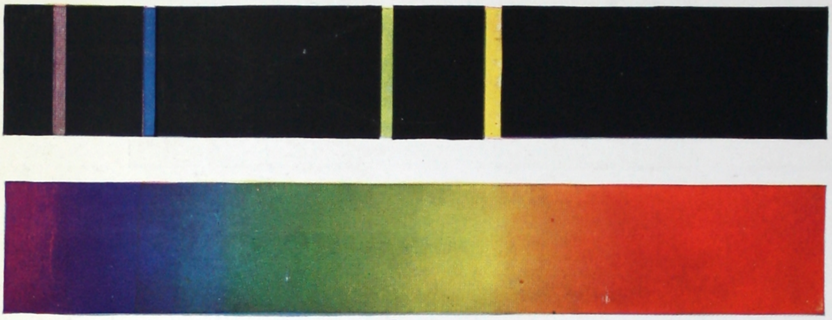


FIG. 5.

The lower band shows the spectrum of standard "white light" (sunlight), and the upper band the spectrum of glowing mercury vapor. The black spaces show the colors that are missing. Note the absence of the entire red and orange end of the full spectrum; these are the rays that contain most of the heat.

How This Natural Defect in the Eye Can Be Overcome

We cannot change the structure of the eye, but we *can* use a different kind of light. This method of overcoming the difficulty has probably occurred to you already. By using a light containing only one color the lens of the eye can produce a perfectly sharp image on the retina.

There is no practical light source at present that gives light of one color only (monochromatic light); but, as we have already seen, there is a commercial lamp that produces four separate colors instead of the continuously blended band of colors and tints. Furthermore, of the four colors produced,—yellow, green, blue and violet,—the blue and violet have a very low visual power compared with the yellow (see curve, Fig. 8), and the green light is very near the yellow in the spectrum, so that there is but little difference in the focus of the two colors. The net result is a light of greenish color, but practically monochromatic so far as the optical action of the eye is concerned. In other words, with Cooper Hewitt light the lens of the eye forms a sharply focussed image on the retina.

In making "soft focus" lenses for photography, one of the means used is to omit the correction for chromatic aberration, thus producing the defect possessed by the eye.

How Acuity Effects Ordinary Vision

You will now understand that the lens in the eye is so constructed that it cannot produce perfectly sharp images of objects seen by daylight or ordinary electric light, which contains rays of all the different colors. Let us now see just how this defect, or "aberration," as the scientists call it, effects our vision. Since the eye is a miniature camera a photographic comparison will help us to understand the subject.

You know that within the last few years "soft focus" photographs have come into quite general use, being considered more artistic than the sharp-focus pictures generally made hereto-

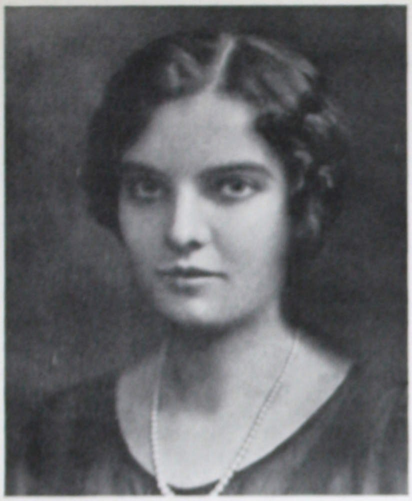


Fig. 6.

A photograph with the focus "softened" just enough to take away the "wiry" sharpness which artists object to as giving an unnatural effect.

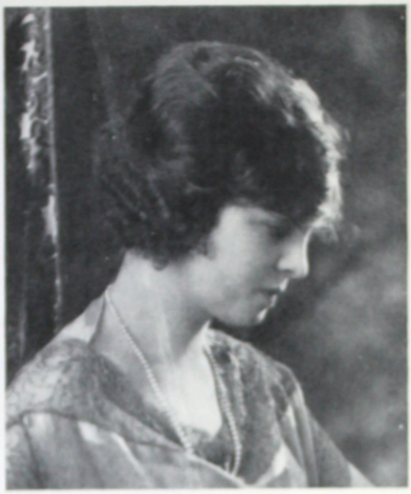


Fig. 7.

A "sharp focus" photograph, showing all the fine details. Photographic lenses are free from the defect of "chromatic aberration" possessed by the eye.

fore. When not overdone this soft effect is undoubtedly more pleasing than perfect sharpness of delineation. Such photographs "look more natural." Why? Because they are more like the actual picture which the mind sees.

Remember, it is the *mind* that sees; and the *image on the retina* is the *picture* it sees. If you cut communication from the retina to the brain (the "optic nerve" is the line of communication), total blindness will result, although the image on the retina may be as clear as ever. On the other hand, the mind can see *only* what is on the retina; anything that interferes with the sharpness or other qualities of this image interferes with the mental impression which we call seeing.

Cooper Hewitt Light Magnifies Small Objects

The most obvious effect of increased visual acuity is to enable the eye to see smaller objects. This fact is stated as a law of physiological optics as follows:

Anything which increases visual acuity produces an effect of magnification.

That this law applies to Cooper Hewitt light has been demonstrated practically in numerous

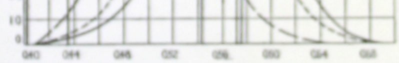
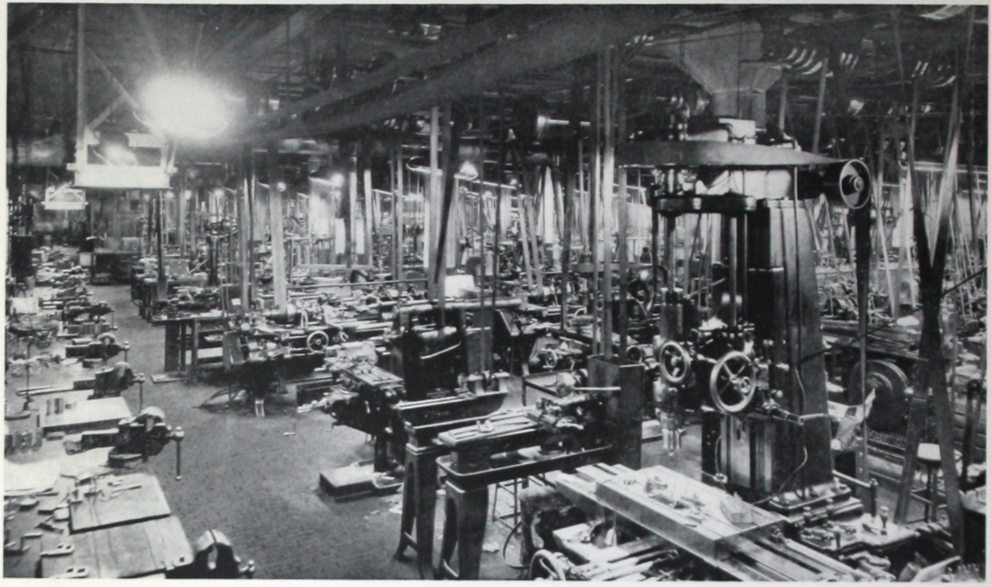


Fig. 8.

Curves showing the comparative visual effect of the different colored rays. Curve A gives the difference at high intensity, Curve B at medium intensity, and Curve C at very low intensity. Note that the yellow of the mercury vapor light (double lines) is near the peak of Curves A and B, while the green line is near the peak of Curve C, which explains the high efficiency of this light.



Tool rooms of modern automobile plants furnish a good example of the relation of visual acuity to manual labor. The increase in acuity and greater contrast of light and shade produced by Cooper Hewitt light enable the operators to work to closer tolerances without eye-strain than is possible under ordinary light.

cases. Thus, a manufacturer of spectacle lenses found that he could not use this light for the final inspection, because it showed up scratches and other defects that were entirely invisible by ordinary light and were therefore not commercial defects.

On the other hand, a prominent maker of photographic lenses found this same effect exceedingly valuable, since all imperfections in high class lenses are technical defects, to be avoided as far as possible.

Another very practical demonstration of the magnifying effect of this light was furnished by the experience of a professional wool grader. It may be stated briefly that the classification of raw wool into the numerous grades of fineness, length of fiber, color, purity, etc., which determines its market value, is done by professional sorters, entirely by sight, whose judgment of the sizes of the fibers thereby becomes amazingly acute. At the first glance at a sample under Cooper Hewitt light this grader said: "Why! this light magnifies the fibers; they look several grades coarser than they really are."

A very extensive utilization of this property of Cooper Hewitt light is found in the manufacture, and especially the finishing, of automobile bodies. In one case, in which the highest class aluminum bodies are made, a saving of $20,000 a year was effected by an installation of this light costing only $6,000.

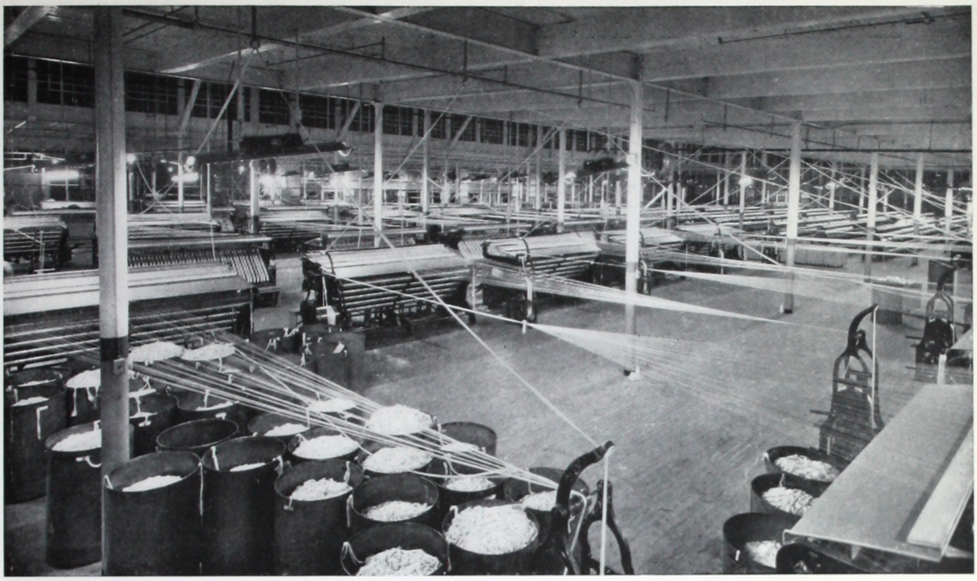
A number of cases are on record in which workmen have been able to dispense with their glasses under this light, the apparent magnification being equivalent to that of the spectacles.

Cooper Hewitt Light Produces Sharper Outlines

Another law of physiological optics may be stated as follows:

Increasing visual acuity increases the contrast between surfaces.

The eye distinguishes objects by differences in



The textile industry, more than any other, makes severe demand upon visual acuity in all its phases on account of the extreme fineness of materials and the multiplicity of threads involved. Cooper Hewitt light has demonstrated its superiority even to daylight for the finer grades of textile operations.

brightness, or as we commonly say, by "differences in light and shade." You see the print you are now reading because the letters are very much darker than the paper; you say they are "black and white," which means simply that there is the greatest possible contrast between them. However, if you will look at this same page from under Cooper Hewitt light you will see that the letters look still blacker; or, as you would probably describe it, they "look a brighter black." As a consequence, their outlines appear sharper; they seem to actually stand out from the surface, like plate printing.

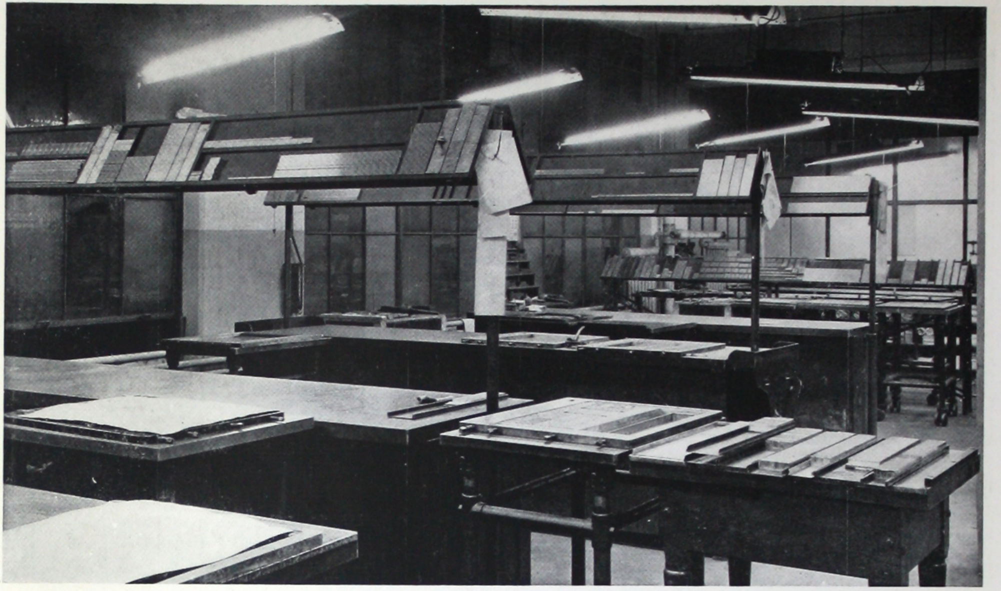
If you were to use different shades of gray ink instead of black you would find that all these different shades would likewise appear more distinct, both from each other and from the paper.

Increased Acuity Gives Quicker Sight

It requires a certain length of time after the image of an object falls upon the retina for the mind to see the object. When a wheel revolves with a certain speed you cannot see the spokes, because they do not remain in one position long enough for your mind to receive the impression.

It has been found by careful scientific experiment that light of one color produces the full visual sensation more quickly than white light, and that yellow and green produce the effect more quickly than the other colors. The difference between light of one of these colors and white light may be as great as two to one in dim illumination.

This agrees with later researches made with daylight, incandescent electric light, and Cooper Hewitt light, to determine the relative length of time taken for the hand to make a motion in response to a visual impression under the different kinds of light. It was found that from five to six per cent. more motions were made in a given time under Cooper Hewitt light than under daylight, and from ten to twelve per cent. more than under incandescent light, the intensities being the same.



In probably no other industry are the advantages of Cooper Hewitt light greater appreciated than in the composing room of the modern newspaper. High speed, coupled with accuracy, make great demand on the operator's eye. Here again the increased visual acuity and speed of vision under Cooper Hewitt light is of greatest value.

Cooper Hewitt Light Enhances Perspective

Perspective is the visual effect by which we judge the relative distances of objects from us. It is produced by differences in visual angle, by variations in light and shade, and to a slight extent by difference in color. The two eyes also act like a stereoscope in making objects "stand out" in their true positions.

By aiding the perception of degrees of light and shade, and by increasing the distinctness of outlines, Cooper Hewitt light enhances the sense of perspective.

That the stereoscopic effect is increased by sharpness of outlines may be seen by a simple experiment, as follows: Look very steadily at the picture shown in Fig. 7, preferably with one eye closed; you will presently get the effect of a stereoscopic picture, more or less perfectly. Then do the same with Fig. 6. You will note that the effect is much more apparent with the sharp focus picture.

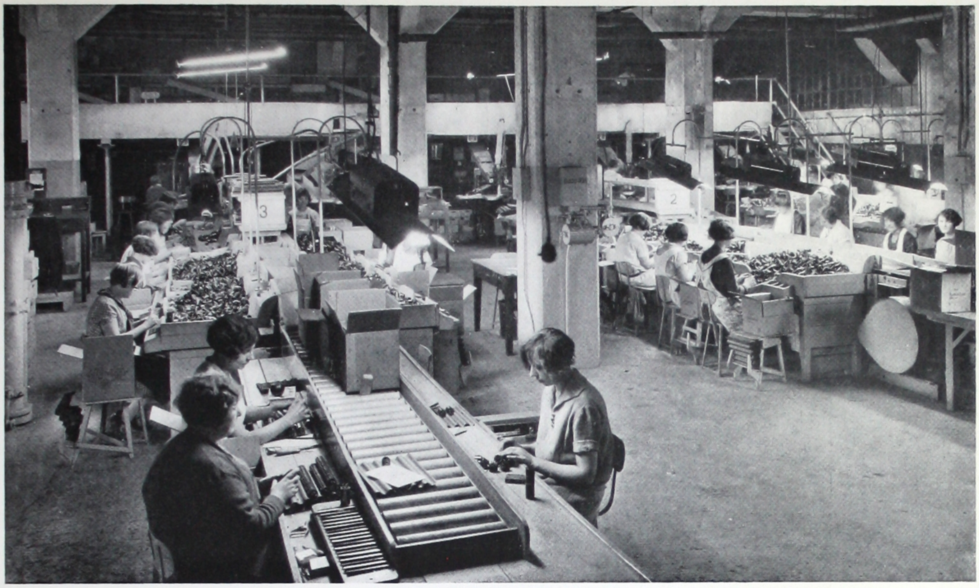
A very convincing demonstration of this law of optics is found in the lighting of spinning frames in the textile industry, where the operator is able to clearly distinguish the position of every individual thread for a distance of nearly a hundred feet.

The detection of dents and irregularities in the surface of automobile bodies affords another practical demonstration, the perception of which is entirely a matter of differences in light and shade.

General Principles

Seeing is the same process regardless of the kind of things seen. Increased acuity is equally advantageous whether fibers and threads of cotton, wool, or silk; scriber marks on metal; scratches on glass or varnished surfaces; or cracks in metal castings, are the objects to be discriminated.

The human eye is an optical apparatus having



Inspection of all types is largely based on the visual accuracy of the operator. Lack of eye-strain and magnification of detail under Cooper Hewitt light has many times proved the superiority of this illumination for all classes of inspection work. In the operation shown, the inspection of black bakelite represents one of the most difficult inspection operations due to the high absorption of light by dark objects, coupled with the necessity of finding minute defects.

a definite plan of construction, and operating in accordance with the general laws of light, just the same as any other piece of optical apparatus. The effects we have given as resulting from the peculiar properties of mercury vapor light are not arguments, but brief explanations; they take place because the eye is built that way.

The general principles of physiological optics apply to every use to which the human eye is put. All eyes are built on the same general plan, and can work only in accordance with their scheme of construction. Good illumination is that which fulfills the requirements of these general principles; the nature of the objects seen simply determines which of the principles, or laws, is of most importance in any particular case.

Remarks

The Cooper Hewitt lamp has not created any new natural laws, but is simply a device for taking advantage of established scientific laws relating to optics and vision, in the production of general illumination for industrial purposes. Marconi did not make any new laws for electricity,—they have existed from all eternity; he showed how to use some of them to improve the methods of transmitting thought. Peter Cooper Hewitt did the same thing for factory lighting when he invented the mercury vapor lamp.

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